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Chapter 5.2

Standardized Power Switch System Modules (Power Electronics Building Blocks)

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The need for lower cost is fueling the drive for standardized system modules or what the Office of Naval Research is calling "Power Electronic Building Blocks --" or just "PEBBs." Increased power density, "user friendly" design ("plug and play" power modules), and multi-functionality are other emerging needs. Digital controls, integrated with higher frequency and more robust power circuits, enable modular power systems with lower size, weight, and cost -- while increasing performance. In this chapter, the requirements, opportunities and issues for standardized power switch system modules will be presented, using experience gained from the PEBB program. First, an overview of the PEBB program is given. Then, the issues of standardized system modules are examined.

Overview Of The PEBB Program

Power electronic technologies are vital to military and commercial industries and are found in factories, robots, electric utilities, airplanes, trains, cars, tanks, ships, submarines, computers, radar, sonar, x-ray, and magnetic resonance imaging. The list is endless. Moreover, environmental issues (clean air and water) require the efficient use of energy and reduced fossil fuel combustion made possible with this technology. In particular, the Navy is planning to use electric drive motors and advanced electrical distribution for the next generation ships. In a very similar way, the Partnership for a New Generation Vehicle (PNGV) is interested in electric drive and advanced electrical distribution for a new hybrid electric car.

The Navy's need covers almost the entire range of power electronic applications, as shown in *Figure 5.2.1*. Furthermore, the Navy is challenged by the need for affordability. The total cost of Navy systems must be reduced. Beyond the cost of purchase, life-cycle costs (such as: manning, maintenance and fuel) must also be reduced. Performance must not be compromised, but reliability and performance must be increased. The Navy must work in cooperation with industry to develop this new equipment.

The Navy and the Department of Energy (DOE) also have similar, complementary goals in the area of electrical power control and modularity. As the Navy becomes "more electric," high power propulsion, auxiliary and weapon systems for ships, submarines, and aircraft necessitate use of intelligent control to manage electric power systems efficiently and to provide reliable, uninterruptable power. DOE's Office of Advanced Transportation Technology needs high volume, low cost electrical power control to produce realistically-priced electric vehicles for mass production. The Navy must develop intelligent, multi-functional, solid-state power control devices, capable of managing a few watts to megawatts to prevent proliferation of high cost, single application devices.

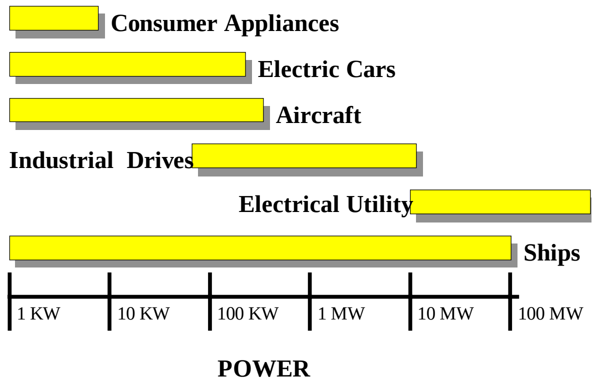

Figure 5.2.1: Power Electronic Applications

The Navy/DOE program will develop a universal, scaleable power control device, the Power Electronic Building Block (PEBB), which delivers high quality, digitally synthesized electric power for multiple applications. The Department of Energy believes that the PEBB will be one of the key enabling technologies necessary for the economic viability of the electric vehicle program. The PEBB offers the opportunity to reduce size, weight and cost of Navy and DOE power electronic systems by factors of 10 or more.

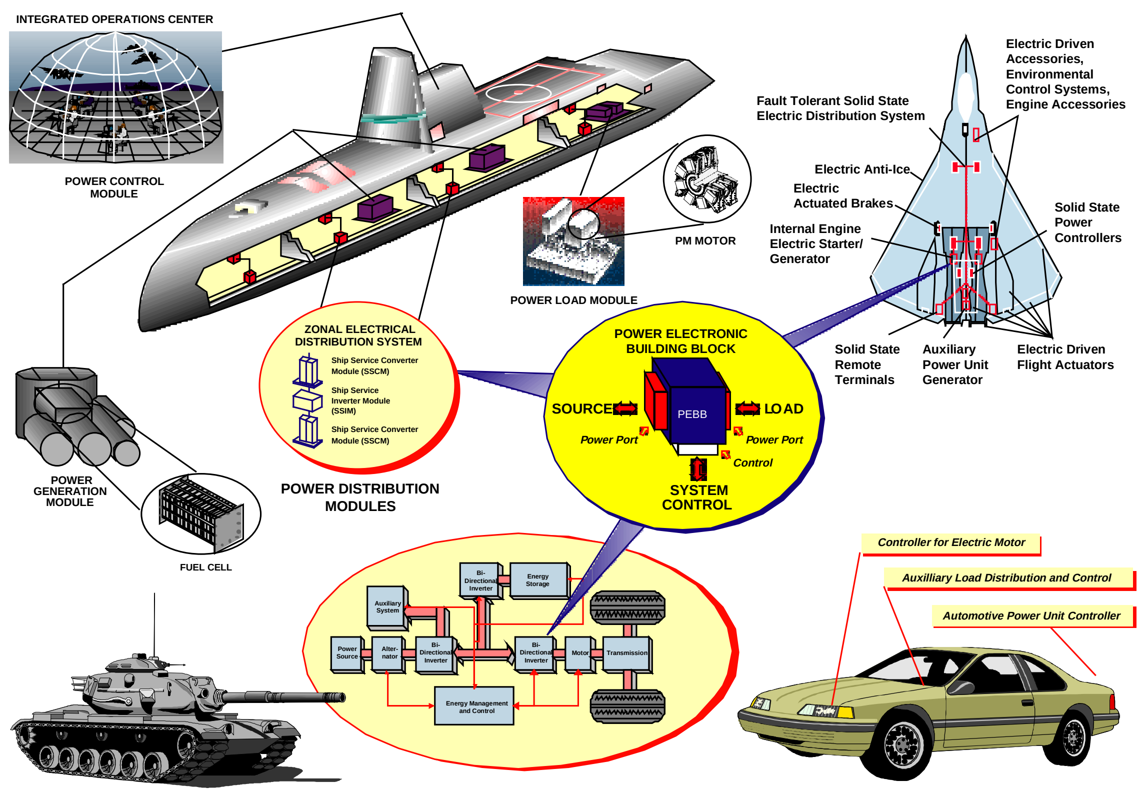

Figure 5.2.2: A Core Power Electronic Technology For Military and Commercial Applications

The Navy/DOE program will build a PEBB and its systems. Using concurrent engineering in cooperation with academia and industry, the program will develop a PEBB and its associated technologies -- creating a commercial-off-the-shelf (COTS) product for military application. It will be a multipurpose, universal device, replacing several specialized devices like circuit breakers, motor controllers, power conditioners, inverters, etc. Since it will be a single standardized unit of manufacture, production of this device in large quantity will reduce its cost. A PEBB, jointly developed with industry, will meet both commercial and Navy specifications. Thus, commercial use of this technology will contribute to even further cost reductions. Potential savings for the military are enormous, if it draws upon the civilian sector to jointly develop a PEBB and its market. A core power electronic technology, *Figure 5.2.2*, is envisioned to be capable of meeting both commercial and military needs.

Furthermore, a technology cascade, as shown in *Figure 5.2.3*, is envisioned which leads to flexible and scalable electric power system architectures. These architectures, based on low cost power controllers, will enable a new age of energy management and control.

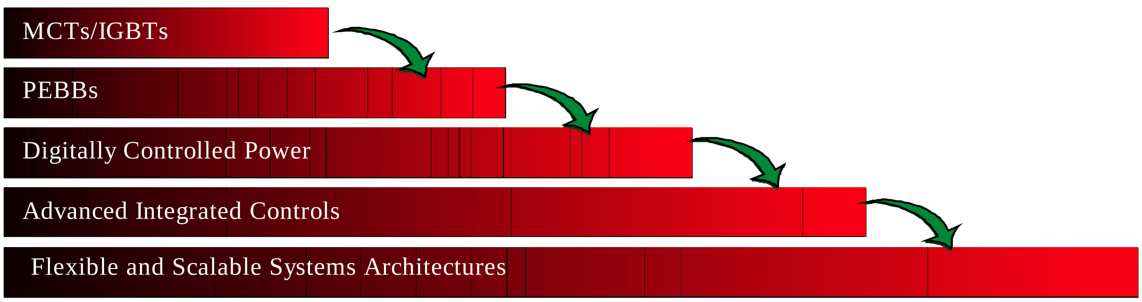

Figure 5.2.3: Technology cascade

The PEBB program challenge is to manage developments in several technology layers simultaneously, as shown in *Figure 5.2.4*. The Navy/DOE development requirements of power density, high speed switching, and micro and power integration are enforced throughout to achieve reduced cost, size, and weight.

A multi-year, integrated research, development, and concurrent engineering approach is underway with intermediate prototype products available throughout the program. Sponsoring several military and commercial demonstrations assures reliability and affordability. At the conclusion of the effort, all aspects of PEBB technologies, their manufacture and their applications, are completed and ready for insertion into Navy/DOE programs, as well as into civilian COTS items.

A "spider" diagram of the entire PEBB program, *Figure 5.2.5*, shows the integration of science and technology with engineering development leading to intermediate products and four targeted PEBB applications. Science and technology are proceeding along the horizontal axis, while products are being drawn from their results in phased intervals. Timelines and milestones for fielding PEBB demonstrations are shown.

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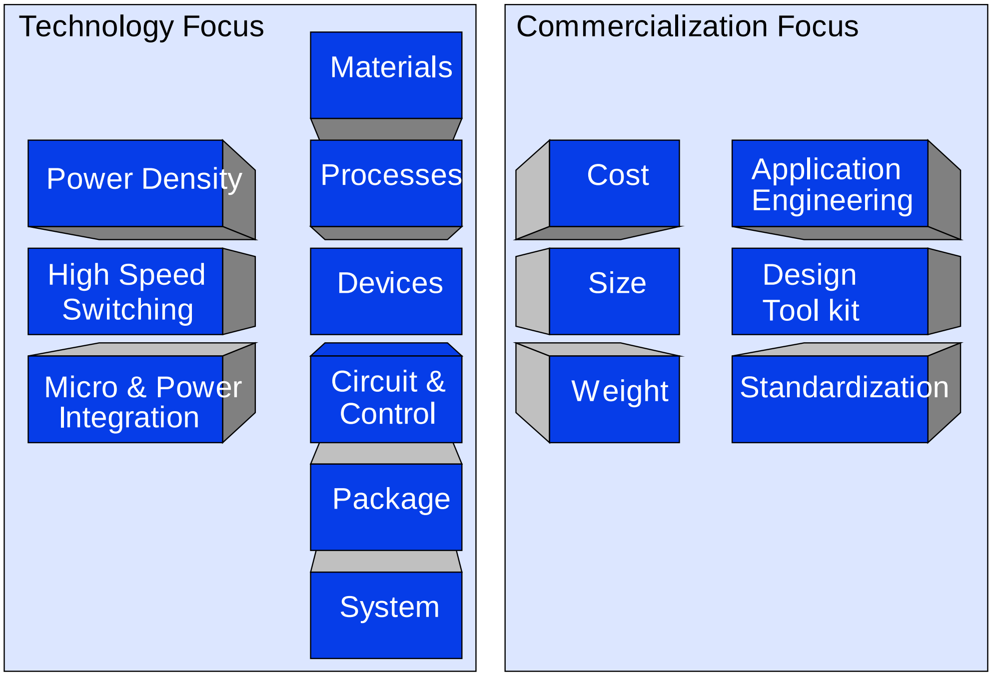


Figure 5.2.4: The PEBB challenge

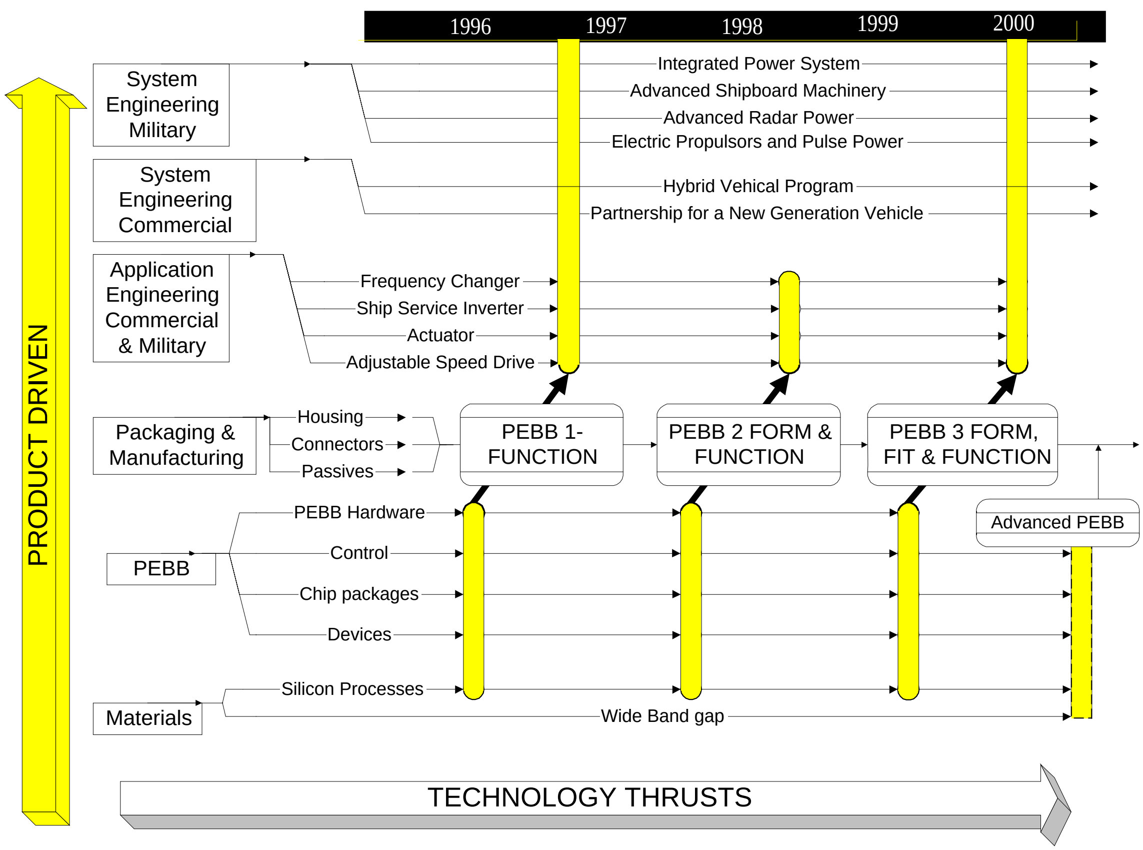


Figure 5.2.5: PEBB program major elements

The PEBB program has four main phases. The first three phases occur between now and year 2,000 and are based on silicon semiconductor technology. The fourth phase is an advanced phase based on silicon-carbide material. In each phase, technological advances are incorporated from the lessons learned from the previous demonstrations.

PEBB-1, the first phase, demonstrated that multiple applications can be performed using the same set of hardware. Each application had its own set of software instructions. PEBB-1 proved that a single set of hardware can perform many functions, such as: motor control, actuator control and power supply.

PEBB-2, the second phase, focuses on developing and defining PEBB form. First order form and fit criteria are established with functions carried forward from the PEBB-1 phase. The micro-controller, gate drives, power devices (diodes, IGBTs and/or MCTs) and some of the passive elements will be contained in a module. PEBB form is defined primarily by packaging considerations such as thermal, EMI, interconnections, interfaces, communications, sensors, control, manufacturing, reliability, passive devices, etc. The interaction of physical constraints, materials and design, bounds the performance of the integrated product. The design team's task is to trade-off between performance, manufacturing, size, cost and weight to meet application requirements. PEBB-2 will also demonstrate two major advances over PEBB-1. First, higher power density switching devices based on trench or UMOS and high density DMOS processing technologies will be realized. They will enable the necessary current density and safe operating area, SOA, improvement. Secondly, PEBB-2 will demonstrate an onboard micro-control system in place of an external controller. The multiple functionality of the PEBB-2 design will be achieved by software programming either stored onboard or downloaded from an external computer. Operation and testing of the PEBB-2 units provides guidance for optimizing the PEBB design proceeding into PEBB-3.

PEBB-3, will demonstrate a fully optimized PEBB prototype in form, fit, and function. The critical technological improvements manifested in PEBB-3 are the use of two-sided cooling, ultra fast turn-off thyristors, distributed/integrated control architecture with software configuration and control.

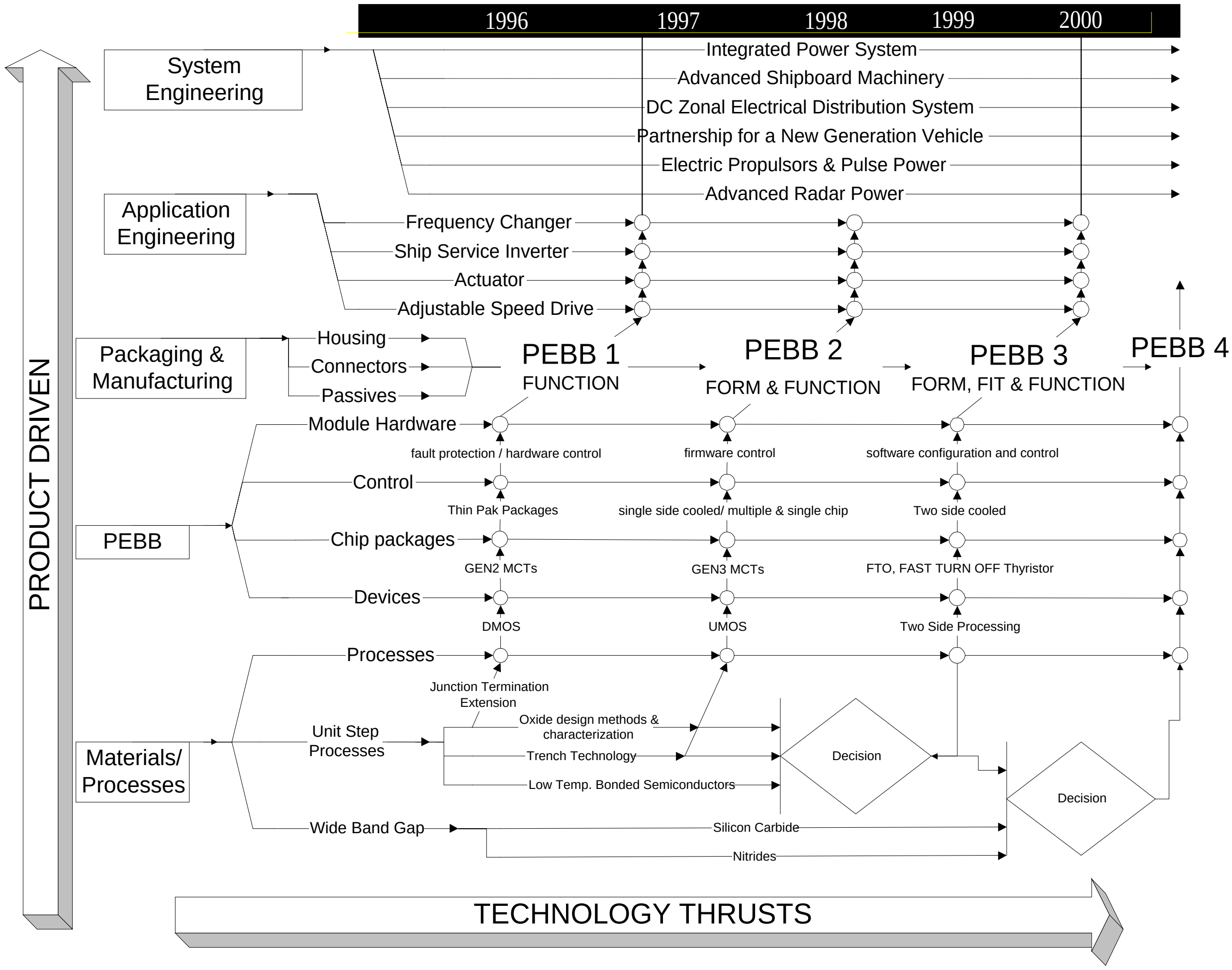


Figure 5.2.6: Spider diagram showing the matrix of critical paths

There is no single critical path through PEBB development, but rather a matrix of critical paths, *Figure 5.2.6*. Each segment of the web must be achieved for each step of the PEBB program to succeed. Parallel investments are made along as many web segments as possible to reduce risk. Ultimately, the objective is to manage the flow of science and technology into products.

Standardized Power Switch System Modules: A New Business

Existing power electronic machines are custom designed for specific applications. In power electronics, everything is application specific. A view of today's power electronic industry is shown in *Figure 5.2.7*. A vender selects his unique type and combination of materials and parts from available suppliers to build his equipment product. Since there is a practical limit to the power electronic design team a vender can afford, the vender's ability to know all, or even a majority, of the possible technology combinations and benefits is limited. Few venders have the depth of expertise needed for a comprehensive power electronics design. In addition to being custom, application specific, and high cost, transition of new materials and technologies into products is very difficult, slow and costly. There is a barrier to new technologies and ultimately a barrier to cost reduction.

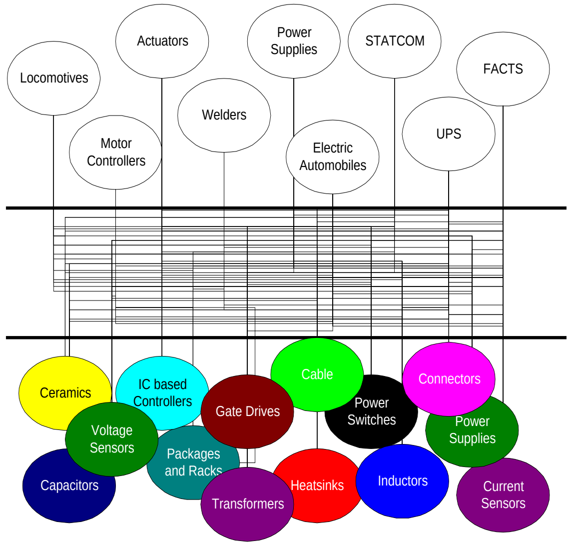


Figure 5.2.7: A view of today's power electronics industry showing applications, each selecting its unique formula of technologies.

A system standard module must reduce the barrier and fill this technology transition gap. Graphically, the proposed relation is shown in *Figure 5.2.8*. The PEBB intercedes between the equipment applications and the many components. This can only be successful if it can fulfill the needs of the applications. Thus, PEBB designs are needed which can support many applications or that are multi-functional.

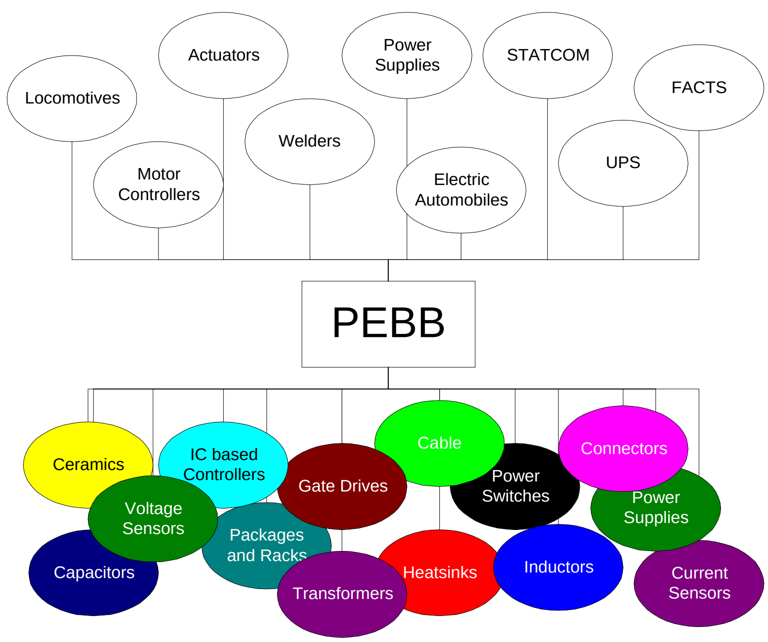


Figure 5.2.8: PEBB reduces the technology transition barrier and design expertise required by the equipment vender.

Multi-functional. Ideally, a PEBB would be a single box that could be programmed to perform all of the power electronic functions desired. From the user's point-of-view, a PEBB is also a universal power processor. It changes any electrical power input to any desired form of voltage, current and frequency output. It should be smart enough to know what kind of power source it is plugged into and what kind of load is plugged into it. It should make the electrical conversion needed, either automatically or as directed by software programming. This would be a power electronic version of “plug and play,” or rather “plug and power.” A system designer, with minimal power background, will be able to construct an electric power machine by using standard building blocks, quickly, simply, and reliably. The specialized design expertise needed by an application engineer is, thus, reduced.

The Navy/PNGV program defines the first PEBB device as a 5 power port device – 2 DC and 3 AC/DC ports as shown in *Figure 5.2.9*.[1] The device corresponds roughly to a 3-phase bridge. The 3 AC/DC ports are programmable wave form ports. Within the bandwidth of the device, the wave forms at these ports are completely controllable by software programming. In addition to the power ports, there is a communication bus (Comm [0…x]), an analog bus (A [0…x]) and a digital bus (D [0…x]).

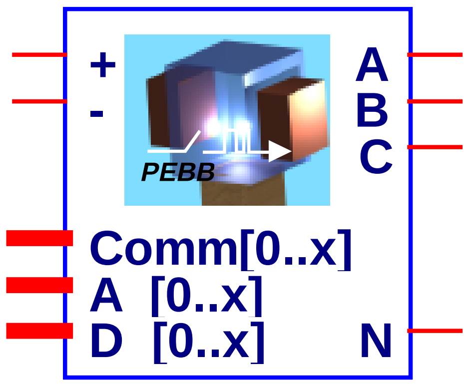


Figure 5.2.9: Power Electronic Building Block 1

Figure 5.2.10 shows PEBB-1 as a 3 phase motor controller. In Figure 11, the same bridge is configured as a dc to dc boost circuit. In both cases, the hardware is exactly the same. The only changes in circuitry are to the connections to the port terminals. The control is changed by down loading new algorithms from a remote computer over a fiber optic communication link. In fact, PEBB-1 can be configured to perform the functions described in *Table 5.2.1*. [1]

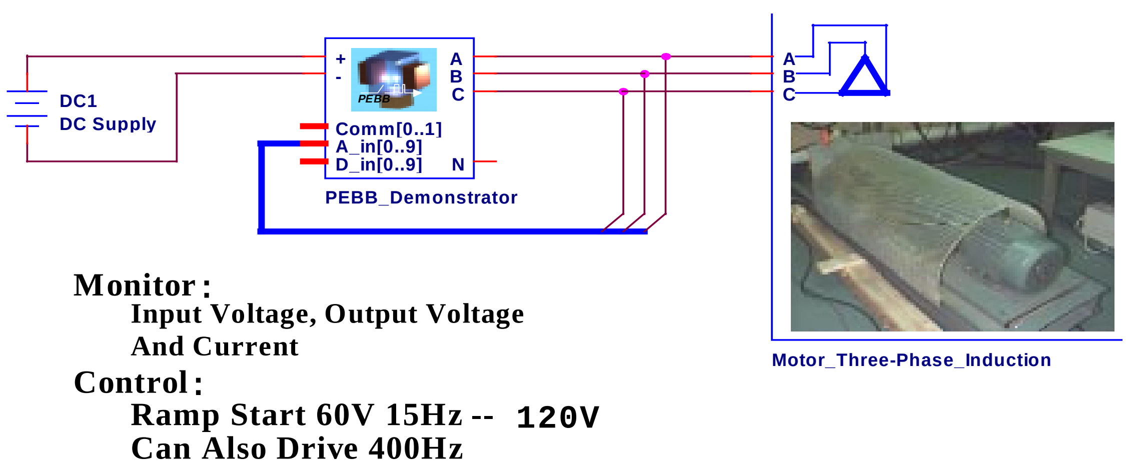
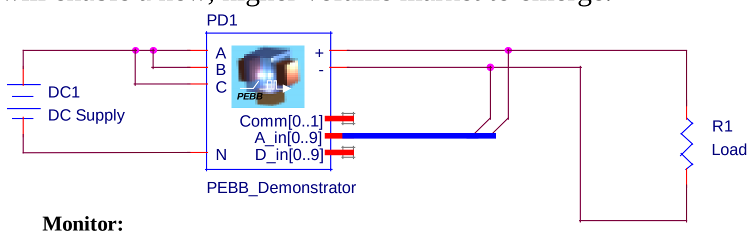


Figure 5.2.10: PEBB-1 as a Three-phase motor controller

Function	Done	Yet To Do
DC to AC Inverter	0-2kHz, 0-120Vac 3Phase, x%THD	450Vac, 320A, 250kW, inductive/nonlinear loads
DC to AC Motor Control	Ramp Start 15-30Hz, 60-120Vac, Constant V/Hz	1/5 - Full speed control, speed regulation, regeneration
DC to AC Actuator Control	Ramp Start, Auto stop when fully Open/Closed, Fwd/Rev	Full Range Valve Positioning, Direct Drive
AC to DC Boost Converter	X2 Boost	Better Control Algorithm, Elim. large circulating current
AC to DC Rectifier	Yet To Be Done	
Frequency Changer	Yet To Be Done	Needs AC to DC Boost or Rectifier + DC to DC Boost
DC to DC Boost Converter	Low Voltage (40Vin - 80Vout), X2 Boost, Voltage Regulation	Test @ Higher Voltages
Linear Motor	Yet To Be Done	Apply multiple PEBBs to perform linear motor operation

Table 5.2.1: Programmable PEBB-1 Functions

A "do everything" power module is not realistic. However, a multi-functional module which could satisfy 80% of the power electronic jobs, is. Just one version of a building block capable of the majority of the day-to-day jobs will enable a new, higher volume market to emerge.



Monitor:
Output Voltage
Control:
Regulate Output Voltage Independent of Load

Figure 5.2.11: PEBB-1 performing DC to DC boost

PEBB-1 was built using today's technology. Innovative control and circuitry were employed; however, the components used were "off the shelf" and the construction was typical of prototype power electronics. The demonstrator illustrates the importance of power circuitry, switches and control to obtaining multi-functionality and reduced cost.

Navy Design Considerations

Filters. *Figure 5.2.12* identifies all the parts needed for standard system modules. The starting point for reducing the cost of Navy equipment was the filter. Filters comprise 2/3 the size and ¾ the weight of Navy equipment. If the size and weight of the filter can be significantly reduced then the entire Navy equipment can be reduced accordingly. There are two fundamental courses of action:

- Reduce the size, weight and cost of inductors and capacitors
- Increase switching frequency

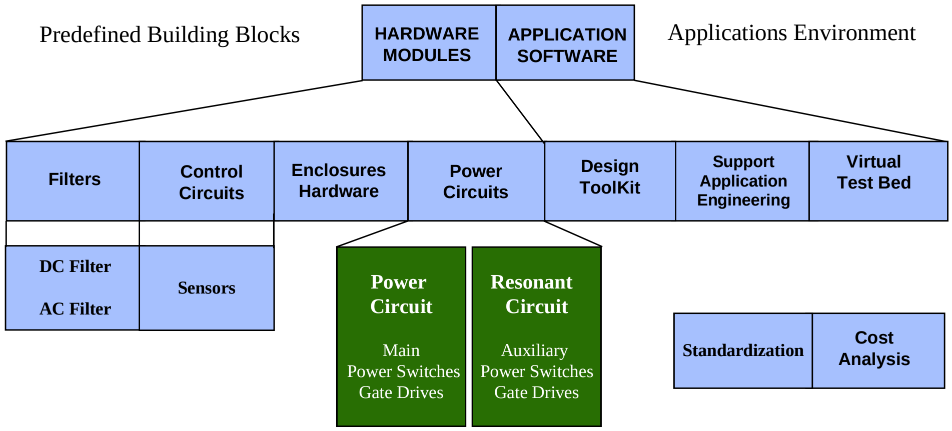


Figure 5.2.12: PEBB Parts. The PEBB Design And Application Environment Uses CAD Tools And Predefined Building Blocks

Reducing the size, weight and cost of filters was not a possibility. They are the forgotten power components. After initial studies, it was very clear that reducing the size, weight and cost of passive components was not a reasonable near term objective.

Thus, increasing switching or circuit frequency and replacing passive filtering with active filtering was a more productive near-term objective. In *Figure 5.2.13*, the general idea of increased frequency and reduced filter size is illustrated. In the Figure, the PWM (Pulse Width Modulation) scheme shown is variable frequency. The pulse widths change and so does the starting point for every switching cycle. The approach minimizes the number of switching events during a cycle of the desired fundamental produced. Thus, switching losses are minimized. In other words, there is no need to switch and adjust the output level, if the output doesn't deviate very much from the desired reference level. During the positive and negative peaks of a sinusoidal wave, the level change is small. *Figure 5.2.13*, shows that large square (positive or negative) pulses can approximate the wave during these portions. However, varying switching frequency produces varying harmonics in the spectrum. The spectrum shown, with a single switching frequency and a clean band between it and the desired fundamental, cannot be obtained using a variable frequency PWM.

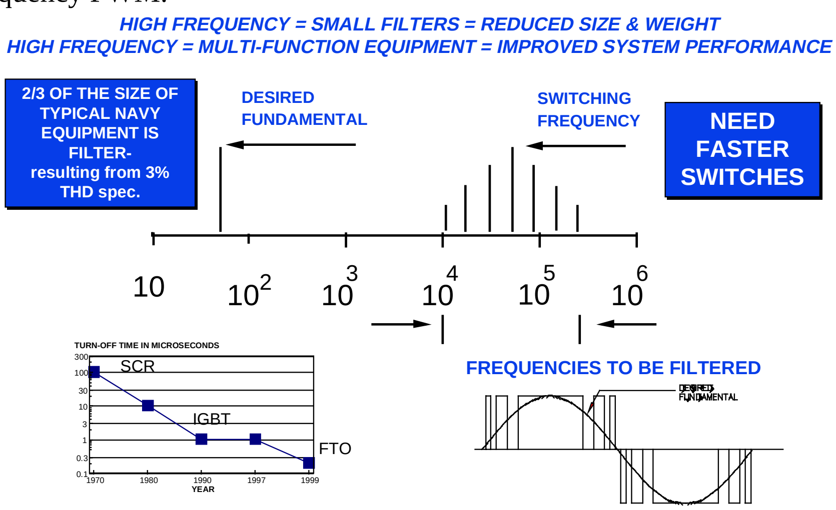


Figure 5.2.13: Filter Characteristics

Fixed frequency PWM (*Figure 5.2.14*) must be used to get the spectrum shown. In this case, the total switching interval or cycle is always the same length of time. The switch duty cycle changes every cycle to produce the desired fundamental. Switching losses are greater than the previous case, because switching occurs every cycle -- even if the output is not different from the ideal reference.

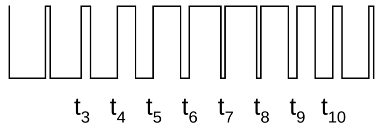


Figure 5.2.14: Fixed Frequency PWM Timing

In the first case, the switching frequency is varied, losses are minimized, and the filter is larger -- because of the additional low frequency harmonics. In the second case, the switching frequency is constant, the filter is smaller and the switching losses are greater. So, for a given input and output filter configuration, harmonic distortion and switching losses can be traded off.

Digital Control Circuits. In the past, the above designs would require completely different control circuits and thus two different machine designs. Today, each of these PWM schemes can be programmed into the same control circuit. Furthermore, one could switch from one scheme to the other, on the fly, if one chooses.

Digital control has really opened up the standard module possibilities. All digital control circuits use microprocessors and EPLD (Erasable Programmable Logic Devices or gate arrays). In fact, control circuits based on these technologies can accommodate just about any control algorithm or scheme with software changes only. One can select state-space, d-q, or sine-triangle.

These new controllers also allow dynamic changes in control during machine operation. An ARCP circuit could run soft switching, hard switching at very light loads, and then back again to accommodate any desired performance. Control schemes can change on the fly from sine-triangle to state-space and back. Increased bandwidth allows machines to be electronically tuned or configured. Motors and actuators previously requiring very tight tolerance manufacturing can use electronic control to accomplish the same result.

Furthermore, electrical machines could have variable quality control. Power quality is dynamic. Motor harmonics vary with the load applied. Harmonics from arc welders and rectifiers also change with time and spatial variables, such as installation impedance. These new controllers can adjust switching frequency and active filtering to optimize efficiency and power quality. Like variable speed motor controllers which vary speed to save energy, variable quality machines will vary filtering to optimize efficiency and performance.

The PEBB-1 control circuit shown in Figure *5.2.15* use two microprocessors and is laid out on two printed circuit boards. The motherboard is about 6-in. x 6-in.. The daughter board is 6-in. x 12-in. During the second phase of the PEBB program, PEBB-2, the control circuit will be substantially decreased in size, weight, and cost by using surface mount technology. In order to reach the final project goals, aggressive application of VLSI technology will be needed --PEBB-3 controller.

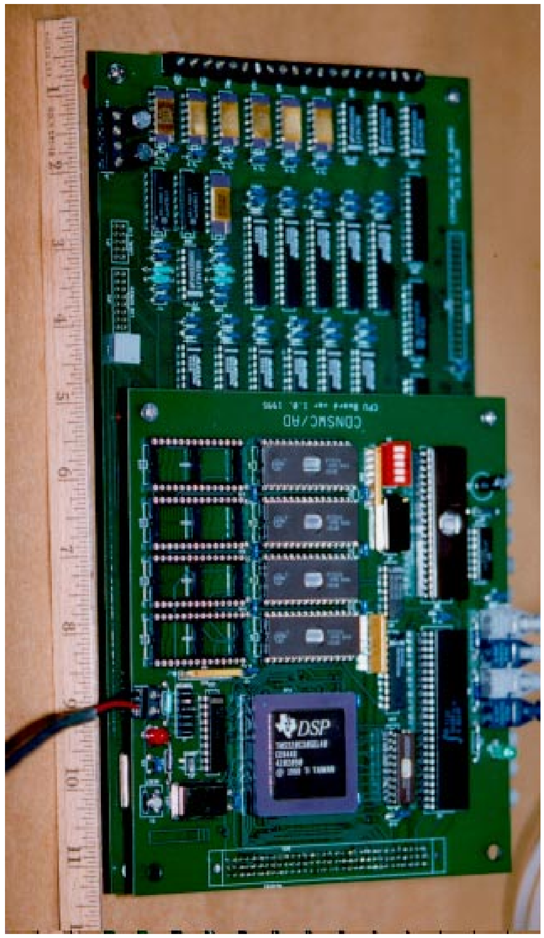


Figure 2.2.15: PEBB-1 Control Circuit Employs Mother and Daughter Boards

Power Circuits. Up to this point, we assumed full-vectored, hard-switching PWM, such as shown in *Figure 5.2.16*. As the rated output power of the converter increases, the losses increase to the point where cooling the switches becomes the major issue. At about 100-200 kW and 20kHz., constant switching frequency, hard switching becomes a real problem.

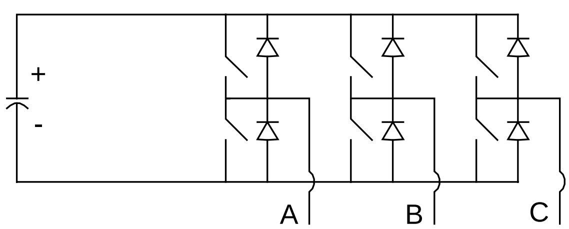


Figure 5.2.16: Full-Vectored, Hard Switching PWM

Soft switching drastically reduces the switching losses by switching when the voltage or current is zero. The VxI product, under either of these conditions, is zero. The Auxiliary Resonant Commutated

Pole topology shown in *Figure 5.2.17* allows full vectored PWM and is soft switching [1][2]. Auxiliary switches are connected to the mid-point of the phase legs (A, B, and C) and to the voltage mid-point of the capacitor bus (V_{mid}). The auxiliary switches are turned on to set the voltage across a main switch to zero. The main switch can then be turned on at zero voltage. The ARCP is a "soft on" circuit. The turn-off state of the main switches is softened by the resonant circuit, like a snubber.

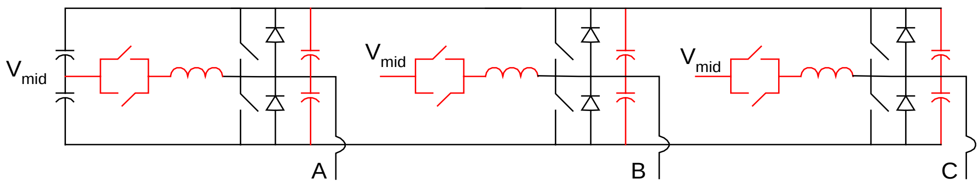


Figure 5.2.17: Auxiliary Resonant Commutated Pole Circuit

The resonant switches are naturally commutated by the half-sine resonant pulse. However, an auxiliary device with turn-off capability allows gate assist during turn-off. Furthermore, gate assisted turn-off increases reliability, decreases timing precision required, and increases circuit performance options.

The ARCP reduces switching losses, but it adds more parts to the circuit. One does not want to give up the filter savings gained by adding auxiliary component cost. The auxiliary devices have to carry peak currents equal to the main switch currents. The duration of these currents is only microseconds. However, transistors have a 1:1 relationship of peak to average current. If one needs to switch 100A DC or for only 1 µsec., one should use a 100A transistor.

In the ARCP circuit, the auxiliary switches will be as large as the main switches if transistors are used throughout. In practical terms, the bridge will now have twice the switches, gate drive circuits, heats and packaging. With costs and the added control complexity, the ARCP is not a good candidate for a standard module -- when transistors are used for all the switches.

If one were to use thyristors for the auxiliary circuits, the story changes drastically. Thyristors have 10:1 peak to average current capability. The problem is that thyristors are not classically good turn-off switches. However, the auxiliary switch is naturally commutated and a perfect application for a new device the PMCT (P type MOS Controlled Thyristor).

Auxiliary circuits, using PMCTs, can be up to 5 times smaller than the transistor main switches. The ARCP also requires a resonant inductor and two resonant capacitors. The dc capacitor link must have a center point. The ARCP is more complex and expensive than the hard switched version. The tradeoff is between filter size, efficiency, control complexity, and cost.

There are no perfect comparisons. Furthermore, all comparisons using today's technology have limited importance, because of all the application specific design issues. However, as an example, venders proposed advanced 250kw inverters for Navy application. A baseline was established as shown in *Figure 5.2.18*. Also, the Navy developed 250kw inverters using ARCP topologies. In *Figure 5.2.19*, a rough order of magnitude (ROM) cost was calculated to assess PEBB-1 progress toward Navy. These costs are rough, and only have significance relative to the baseline of *Figure 5.2.18*.

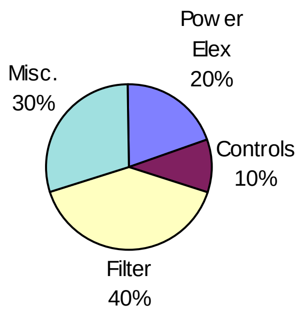


Figure 5.2.18: Baseline, Total $90,000

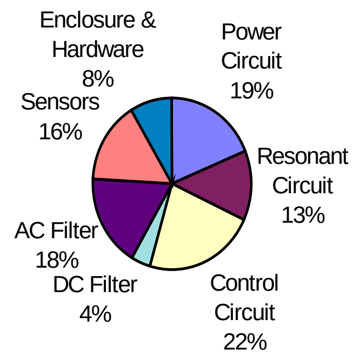


Figure 5.2.19: PEBB-1 ROM, $53,000 Total

First, the total cost of the inverter was reduced using the ARCP. Control cost stayed the same and, thus, became a greater percentage of the resultant ARCP design. The power circuit cost is lower, but its percentage of the machine cost is the same.

The big change was in the filter. The DC and AC filter size dropped from 40% of the machine cost to 22% -- 2/3 reduction of the original filter cost. This was offset by the added resonant circuit and its cost. The net result was a 40% cost saving for the whole inverter.

The ARCP is not assumed to be right for all applications. Furthermore, there are many possible circuits such as: Auxiliary Resonant, Resonant DC Link, Matrix Converter and others. The Navy is continuing to investigate other power circuit topologies. Reducing switching loses with soft switching was a key technical advance needed by the Navy.

At lower power, the jury is still out. Hard switching may be a better solution for many applications. Motor drives tend to be very simple, particularly if insulation and bearing wear are not issues. The added complexity of soft switching may be a luxury for lower power motor drives.

In any case, there are many single phase or multiphase applications, not just the three-phase emphasized herein. There will never be the single do everything power circuit. Power circuits, as with all standard module technologies, will continue to evolve. Standard modules will have to accommodate all of these variations and much more. Modules with flexible internal chip interconnections are being explored. Standard system modules based on a limited number of snap together sub-module is another alternative for flexible yet standardized circuit solutions. Component integration is the next crucial step.

Component Integration

Multi-functionality, without component integration, only solves part of the problem. The cost of power circuit assembly must be made as low as possible. Power electronic machines, particularly from 1kW and above, are three dimensional sculptures. Wiring, component layout, shielding, heat removal, etc., require expensive assembly labor. Component and module interconnections must be as labor-free as possible.

The main challenge of the next phase of the PEBB project is to define the form of a PEBB or standard module. This will be the foundation of component integration which will be fully realized when the final function, form, and fit of a PEBB are established by the third phase of the PEBB program, PEBB-3.

The module problem starts with the struggle between wanting a continuously variability design process and the need to standardize on a few variations that can be produced in high volume. As in the microprocessor, the transistor or switch is a basic element of the inverter. *Figure 5.2.20* shows transistor configurations that can be connected to form any power circuit one wishes [3]. Connections are left to the user, with all the cost, reliability and labor problems. A module based on this approach can be made in high volume, but module savings are lost in all the added costs of connections. If the user were left to make the millions of transistor connections in a microprocessor, then any computer configuration would be possible, but the process would be costly and impractical.

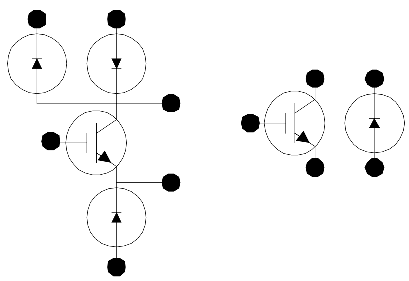


Figure 5.2.20: Power Switch Configurations

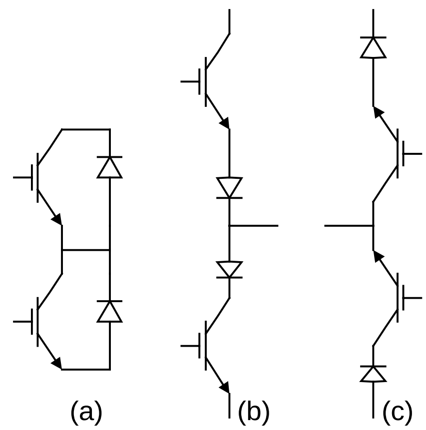


Figure 5.2.21: Configurations for AC/DC, DC/AC and DC/DC Conversion

The Virginia Polytechnic Institute and State University team, headed by Fred C. Lee, defines a PEBB derived from basic switching cells[3]. A phase leg with diodes in anti-parallel, *Figure 5.2.21* (a), can be used for AC/DC, DC/AC and DC/DC conversions via boost rectifier, voltage source inverter, and half/full-bridge configurations. A phase leg with diodes in series, *Figure 5.2.21(b and c)*, can be used for AC/DC, DC/AC via buck rectifier or current source inverter configurations [3].

In *Figure 5.2.22*, phase legs with anti-parallel diodes are shown in various converter topologies. *Figure 5.2.23* shows converters with a series diode configuration. Both families of converters cover a wide range of user applications and utilize common switching cells. Furthermore, *Figure 5.2.24* shows AC switch configurations.

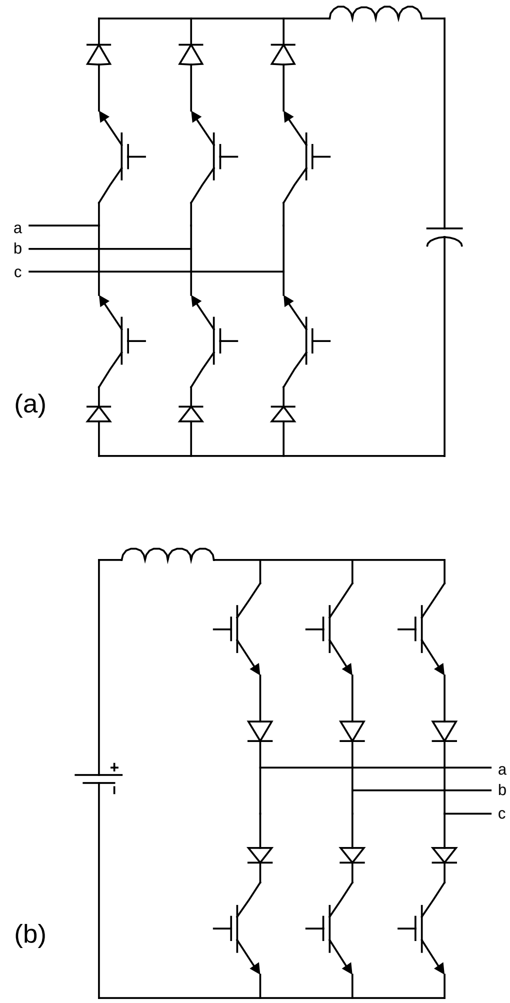


Figure 5.2.22: Family Of Converts Based On A Series Diode Phase Leg

As an aside, an AC switch formulation without diodes is possible. It will require symmetrical blocking switches which have yet to be developed for the newer MOS-Bipolar devices. IGBTs, MOSFET, and MCTs available today are asymmetrical blocking devices which only block voltage in one direction. In the other direction, they block only fraction to rated voltage.

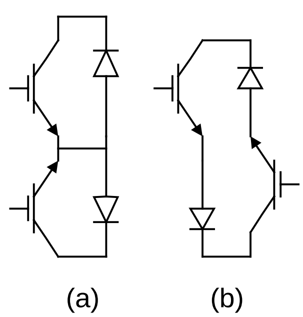


Figure 5.2.23: AC Switch Configurations

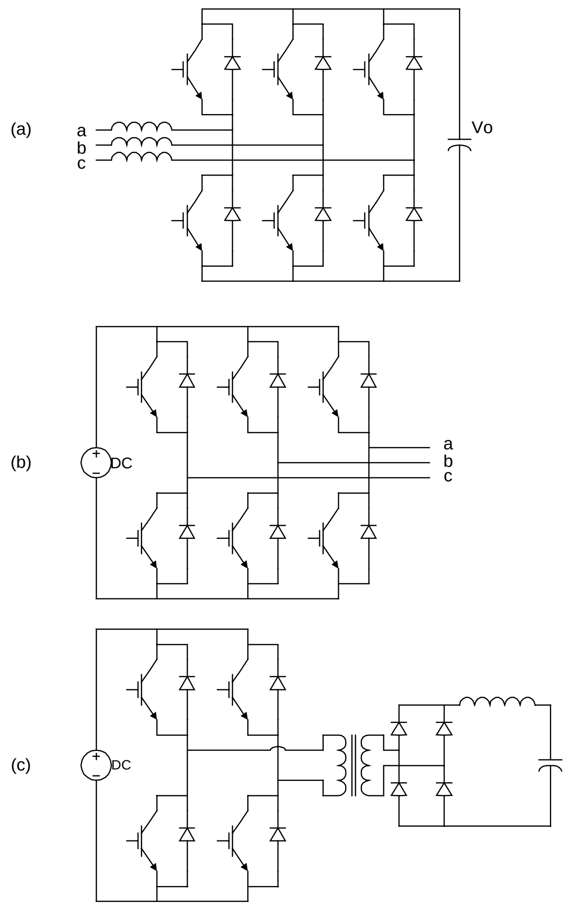


Figure 5.2.24: Family of Bridges Using Phase Legs with Anti-Parallel Diodes

In any case, there are many potential standard power circuits which could provide the 80% solution needed. Furthermore, each of the hard switching circuits of *Figures 5.2.22* and *5.2.23* could also be made soft-switching by adding an auxiliary circuit based on the ac switching cell shown in *Figure 5.2.24*. Other resonant components such as capacitors and inductors are needed. However, it is conceivable that circuits based on these common switch cells could be modularized and then combined with auxiliary modules, based on common AC switch cells, to extend performance where required.

The University of Wisconsin-Madison team, headed by Tom Lipo, defined an application-level PEBB or APEBB[4]. The APEBB, shown in *Figure 5.2.25*, has a higher level of complexity – on par with that defined by PEBB-1. These APEBBs could be combined with others and higher level control to perform system functions. As shown in *Figure 5.2.26*, application level APEBBs could also have multiple PEBB modules to perform functions, such as: voltage scaling, energy storage and impedance matching, within an APEBB.

Moreover, there can be temporal partitions for an advanced system of many APEBBs[4]. Each system layer would have clearly defined control boundaries, as shown in *Figure 5.2.27*.

Each control boundary would have a time frame associated with it. Hierarchical control functions combined with temporal partitions allow independent and parallel development of system elements. This also enables an "open architecture" capability in the final system.

Component Interconnection

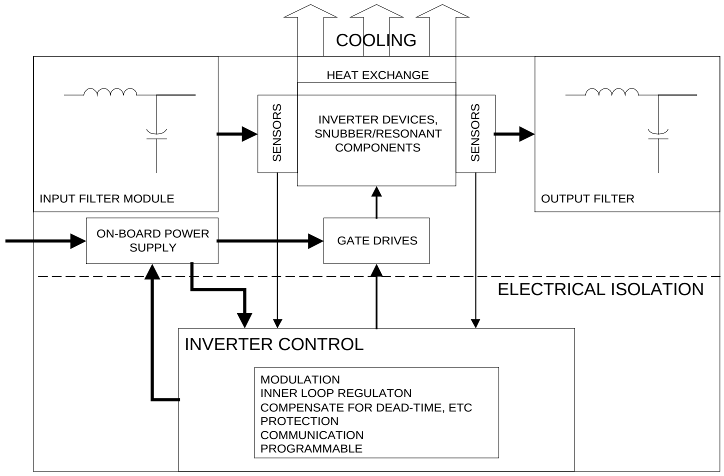


Figure 5.2.25: APEBB

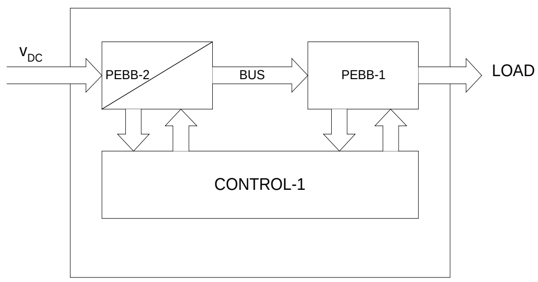


Figure 5.2.26: Application level APEBBs

The APEBB diagram of *Figure 5.2.25* shows a complete inverter with all of its issues such as: cooling, electrical isolation, on-board power, sensors, etc. *Figure 5.2.28* shows some of the parts of a PEBB power circuit – switch modules, capacitors, inductors, etc. *Figure 5.2.15* shows control circuit parts. The trick is: to get all these elements into a neat modular organization, as shown in *Figure 5.2.25*.

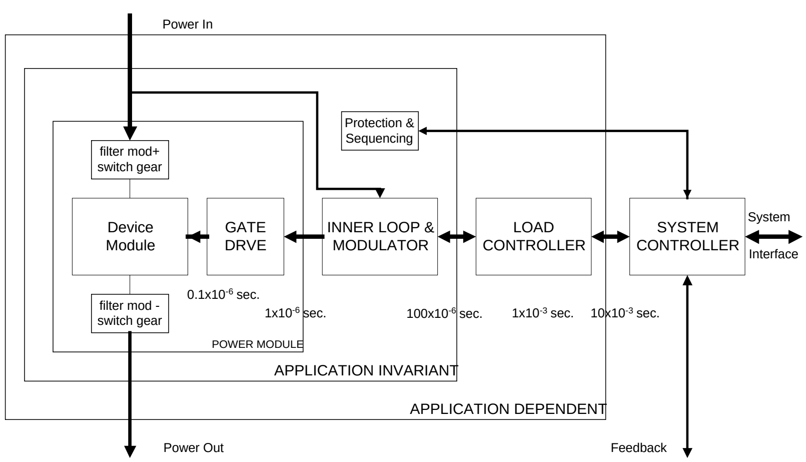


Figure 5.2.27: PEBB Hierarchical Control And Temporal Partitions

A switch module is shown in the upper left corner of *Figure 5.2.28*. In reality, the switch module is a very small part of the inverter. The large cylinder capacitors dominate remaining views counterclockwise in *Figure 5.2.28*. In the lower left corner, a three layer laminated bus is drawn with cylinder capacitors, the switch modules and ceramic capacitors connected to it. The whole exercise seems to be about putting square pegs into round holes and round pegs into square holes, and bonding square and round pegs together. As stated earlier, power electronic machines are more like custom works of art than a mass produced technology.

The control circuit is better organized, as shown in *Figure 5.2.15*. Furthermore, surface mount and VLSI technologies will enable further improvements in electronics packaging. However, the operating temperature of microelectronics is lower than power electronics. EMI generated by the power circuit can be disruptive to the control electronics. Thus, layout, shielding and thermal management are major issues when packaging microelectronics with the power electronics.

Assembly cost, expansion of new applications, and the true realization of the "second electronic revolution," will require simultaneous resolution of two objectives:

- Decrease the cost of automation
- Increase volume to spread out the cost of automation

Automation cost reduction can be summed in two approaches: reduced automated machinery costs and reduced complexity of component assembly. In part, the problem of automation cost is circular. Power electronics is a significant part of the cost of automated machinery; so eventually, reduced power electronics' cost will reduce the cost of automation.

Reducing the cost of component assembly will require a new system of component interconnection. Just as VSLI has substrates and electronics has circuit boards, there needs to be a basic building structure for power electronics. Once parts get beyond printed circuit board sizes, there are no industry-wide interconnection standards for power devices, capacitors, and inductors. Today's higher frequency circuits also use laminated buses to minimize circuit inductance. Yet, all of the component connections to these expensive buses tend to be highly inductive and labor intensive. Component interconnection is one of many issues carried into the PEBB-2 development.

Conclusion

A multifunctional PEBB has been described and demonstrated. Digital control circuits are key for the next generation of power electronics and enable a wide range of programmable standard module control options, with little or no hardware changes. Furthermore, control circuits have surface mount and VSLI technology options to further reduce their size, weight, cost. Power circuits are also capable of providing many options for a wide range of programmable performance. Their performance can be extended by the use of auxiliary circuitry which is made practical by PMCT devices.

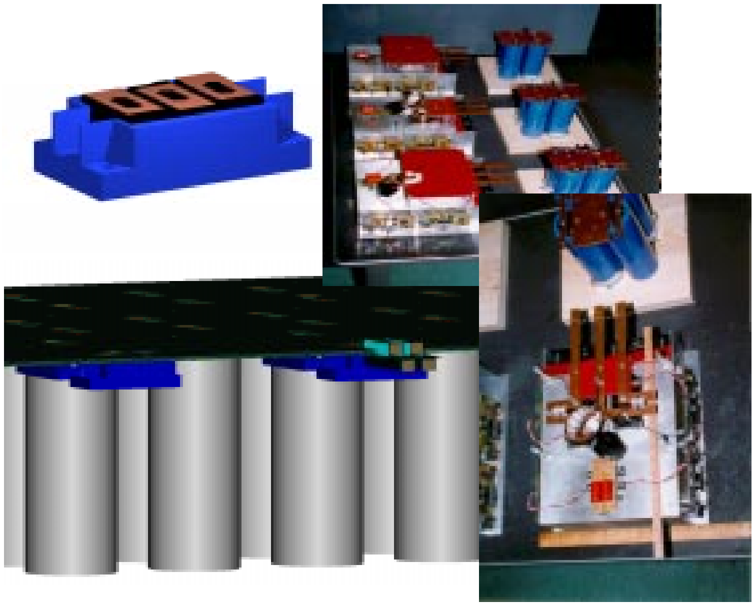


Figure 5.2.28: PEBB Inverter

Integrating power electronics with microelectronics is one major issues in the program. A plan for PEBB integration has been presented – feasible at least on paper. There may be, and most likely are, other such plans and standard module designs. The real standard power module solution ultimately comes from industry after a process of maturation. In this case, the maturing process will also require new manufacturing technology.

Passive components dominate the present PEBB designs. Smaller capacitors and inductors with higher operating temperature are needed to realize a compact standard system module. In lieu of adequate components, higher frequency switching will be employed to reduce the filter inductance and capacitance needed. Ultimately, interconnection of these components with the other power and microelectronics devices becomes the root of the manufacturing problem and cost.

Although not discussed in the chapter, sensors are another major component problem. Higher bandwidth machines require higher bandwidth sensors. All machines need lower cost sensing circuitry.

The next step is to define PEBB form. The electrical, mechanical, and thermal form of a standard system module must be defined in a consistent, systematic, manner. The Navy/DOE PEBB program has taken up this challenge in the PEBB-2 phase of the program. Ultimately, the success of this effort will depend on the support and participation of the whole power electronics community.

Acknowledgments

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